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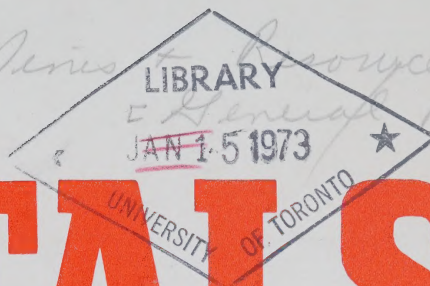


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*Canada,
Dept. of Eneirgy Mines & Resources*
finding out about

METALS



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At the experimental foundry in the Physical Metallurgy Division of the Mines Branch, molten steel is poured from an electric furnace.

A wide variety of new alloys are developed and tested here. Temperatures, rates of heating, pouring techniques, cooling rates, and the proportions of metals used must all be carefully controlled.

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finding out about
METALS

Department of
Energy, Mines and Resources, Ottawa
Minister : Donald S. Macdonald
Deputy Minister : J. Austin

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History and Before

Man is at least a million years old. Our ancestors spent most of this immense stretch of time huddled in caves devouring the beasts around them and sometimes each other, nibbling berries, nuts and roots to vary the taste.

About 30,000 to 40,000 years ago, man became subtly aware that certain naturally shaped stones were more useful than others for scratching a living together. Round rocks, for example, were more effective hunting weapons and sharp stones better cutting tools. Our forefathers pondered the matter and slowly, painstakingly began to shape stones, wood, bones and sea shells into crude weapons and implements.

And thus began the age of modern man.

Nearly 8,000 years ago, man first encountered metal. Gold. Shiny, yellow nuggets of gold gleaming in river gravel attracted man as he searched for stones. But it proved a disappointing substance. Too soft for weapons or tools, gold acquired limited value over the years for hammering into decorative shapes and ornaments.

Looking for gold, man picked up larger lumps of dark reddish stone that when hammered seemed like gold, though its behavior was different. Native copper hardened on hammering and could be sharpened into weapons and tools. The red stone was obviously more useful than the yellow one.

Over the next 2,000 years, man discovered that native copper could be annealed (softened by heating) and made plastic and could be forge-welded by hammering two or three heated lumps together. And so the first industrial metal was born.

Silver was the third metal to be discovered. Like gold, it was regarded as a useless stone mainly of ornamental value.

Lead, which is closely associated with silver in nature, probably was found at about the same time. Its properties however, were of little value for prehistoric applications since no lead has been found so far in archeological remains of that period.

The real Metal Age did not begin until man learned how to cast metals, to melt them, and to pour the molten mass into moulds of prearranged shapes. This discovery probably occurred by accident around 5000 B.C. in Mesopotamia or Egypt.

Over the next thousand years, man by chance succeeded in smelting copper from its ores. This development is one of the great turning points in the history of man, comparable to the discovery of artificially produced fire.

The availability of man-made copper drastically changed man's way of life because the previously scarce metal could now be used generally.

Today, copper is vital as a conductor of electricity. In fact until recent years, copper was used exclusively as a conductor throughout the world.

The discovery of alloying or blending, probably by the accidental addition of tin ore during the smelting of copper, initiated the Bronze Age which lasted from about 3500 B.C. to 1500 B.C., until the isolation of iron.

Bronze casting, a craft of the ancient Egyptian and Chinese cultures, became refined into a rare art by the Greeks and was popularized into mass production for cannons and church bells by modern man.

Iron became an important metal about 800 to 700 B.C. as the most practical material for weapons, machinery, etc., and has retained its primacy ever since. Today, iron touches every human life; every industry and most major activities demand the use of iron. The annual world per capita consumption of iron and steel in 1969 was 352 pounds as compared with 10 pounds for the non-ferrous metals, copper, lead, nickel and zinc.

Modern Metals

At the end of antiquity mankind knew only seven metals; between 1500 and 1700 A.D. another three were discovered; in the 18th century 14 more were found and since 1801 another 51 have been isolated. The most important of these were zinc, nickel, magnesium and aluminum.

ZINC, though used for almost 2,000 years in the production of brass and nickel-silver, was only isolated in 1743 by the German chemist A. S. Maggaff. Today, zinc is a valuable alloying addition to many aluminum, copper and magnesium casting alloys. Vast quantities are used in the production of batteries, decorative hardware and castings.

NICKEL, known in the form of its ores for thousands of years, was isolated in 1751 by the Swedish scientist A. F. Cronstedt. Since it is highly resistant to corrosion it is an essential ingredient of stainless steel and the base material for most coinage systems around the world.

MAGNESIUM, discovered by H. Davy in 1808, was isolated by A. Bussy in 1828. It was not used industrially on a practical scale until the 1920's. The lightest structural metal known to man, magnesium today finds application in the aircraft and space industries. One of the most notable single uses of magnesium castings is the 28-pound crankcase of the Volkswagen automobile.

ALUMINUM compounds have been used for at least 7,000 years in the production of pottery, especially chinaware, but metallic aluminum was separated by the Danish scientist H. C. Oersted only in 1825. Over the last 50 years the consumption of aluminum has taken a meteoric rise until today it is the most important metal after iron.

Metals in Canada

Canada is richly endowed with mineral wealth. But in relation to its vast territory, the mineral content of Canada's soil is not spectacular; in fact it is lower than that of many other parts of the world. What makes Canada the third-largest mineral producer in the world, following the United States and the Soviet Union, is partly the ability to economically extract metal from low-grade ores, and partly the know-how to operate smelters and processing plants to produce metal with a competitive edge on world markets.

(See table on following page)

The Future

There is no danger that Canada will exhaust its metal resources in the foreseeable future. Indeed there is every hope that rich deposits remain to be discovered in untouched areas. But that is in the long term. In the short term, Canada's position as a leading world exporter of metals depends more and more on how effectively processes can be adapted and developed to extract metal from the huge known low-grade deposits which at the moment are economically unattractive.

What precisely is Canada doing about it?

Total Canadian Production

	1960 (000 tons)	1965	1970
Copper	439.3	507.9	673.7
Iron	21,550.8	39,958.9	53,209.8
Lead	205.1	291.8	383.2
Nickel	214.5	259.2	308.0
	(000 troy oz)		
Gold	4,628.9	3,606.0	2,357.6
Silver	34,016.8	32,272.5	44,282.7

Canada's Rank as World Producer (1969)

Copper.....	3	Zinc.....	4
Iron.....	4	Gold.....	3
Lead.....	3	Silver.....	2
Nickel.....	1		

The Mines Branch

The Mines Branch of the Department of Energy, Mines and Resources is at least part of the answer.

Established in 1907 to investigate coal deposits under the Mines and Geology Act, the Mines Branch quickly expanded to meet the technical information demands of Canada's fledgling mining industry. It has led the research pack in metallurgy and mineral processing ever since.

Today, the Mines Branch offers industry a pool of experts on Canadian mineralogy and on every phase of metal mining and processing from ore to finished metal casting, sheet or extrusion product.

Though science and technology are constantly changing, the aims of the Mines Branch have changed little over the years. They are simply to improve existing technology, to adapt known methods or to develop new ones for specific Canadian mining situations in order to increase the efficient use of Canada's mineral resources and to enhance the marketability of Canada's metals on world markets. In other words, the Mines Branch carries out any mineral research which falls outside the scope of a commercial company concerned with a dollar return to shareholders, yet which could benefit the Canadian economy in the future. As a result, the Mines Branch is deeply involved in such projects as the development of techniques for the economical extraction of iron, uranium, etc., from common low-grade ores, and the reduction of pollution from smoke stacks and mine tailings.

In addition to basic research, the Mines Branch will act as advisor, on request, to anyone with a mineral or metal problem. The Branch will not compete with industry but will suggest competent consultants if necessary, or undertake to solve the problem itself if it is of possible national economic interest.

The Mines Branch operates probably the most sophisticated laboratory

and pilot-plant facilities for the study of metals in Canada. To the uninitiated the equipment is a jungle of electron 'this' and computerized 'that'; only the professional can appreciate with what technical know-how and to what depth each problem is studied.

The Branch participates in committees for the development of international and national standards and specifications of such bodies as the International Standardization Organization and the Canadian Standards Association. In addition, it takes part in the activities of such international technical agencies as the American Society of Metals, the Organization for Economic Cooperation and Development and the World Energy Conference.

The effectiveness of the Branch? That can only be judged by the acceptance of its findings by the industry it serves, as the next few pages tell.

What goes on at the Mines Branch

The Mines Branch is deeply immersed in every step of metal production, from the identification of ore compositions to the improvement of metal properties.

Ore Identification

A pure metal deposit, the ultimate dream of every prospector, is rare in nature. Mostly, metals occur in an almost infinite number of combinations with other metals and elements in complexes known as ores. Each ore, because of its source, location and geological history, is unique in nature and composition.

At the Mines Branch, identifying an ore is not just a matter of defining its composition or of evaluating how much of the valuable mineral it contains. Each ore is analyzed in depth physically, chemically and electronically to determine in detail the exact make-up and structure, to obtain answers to such questions as to what elements is the metal attached ? and how ? what are the chemical linkages ? the crystal shape ?

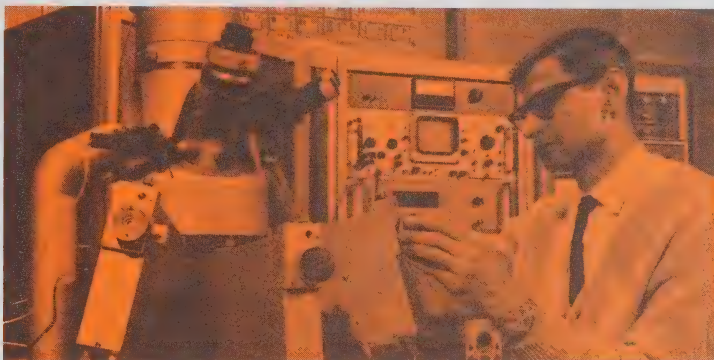
At first glance, in-depth analysis of simple ores may seem a waste of time and effort. But, in fact, specific knowledge of the structure of any ore can often save thousands of dollars by pin-pointing exactly the treatment required to extract the metal.

The Mines Branch will analyze any ore sample that does not respond to normal analytic procedures of commercial assay laboratories or that appears to show unusual characteristics or unknown elements.





1 A mineral crystal is rotated on this X-ray diffraction unit so that the structure of a unit cell can be determined. The X-ray photograph gives information from which a three-dimensional atomic model of the crystal can be built.



2 A mineralogist examines an atomic model of a sulphide mineral. The model of the crystal's unit cell is constructed from X-ray diffraction data. The balls in the model represent the relative sizes of the atoms, and the links between the balls represent the electro-chemical bonds that hold the atoms together. By studying the structural features of the unit cell, the scientist obtains information on the relationships between atoms, and on the nature and strength of the bonds holding them together. This information will help him to understand and develop new processes for extracting metals from sulphide minerals; before he can expect to obtain maximum efficiency in taking the mineral apart, the scientist should understand how it is put together.



3 Using an electron microprobe, a scientist analyzes a mineral sample. A beam traverses the particles in the sample bombarding them with electrons. This causes the particular elements in the sample to give off their characteristic X-ray wave-lengths. These wave-lengths are picked up by one of the three spectrometers (one of which the scientist is adjusting). The characteristic wave-length of any element may be selected and recorded on a screen. Thus the composition of a mineral particle is quickly and precisely determined. Developed by the French in the 1950's, the electron microprobe is a powerful tool, commonly used for analyzing small particles in mineralogy, metallurgy and geology.

4 By a procedure called atomic absorption, the metallic elements present in a solution containing a dissolved mineral sample can be quickly and accurately measured. A lamp emitting the colour characteristics of the element for which the solution is being tested projects a beam of light through a burner flame. A small amount of the solution is injected into the flame changing the colour. The intensity of the characteristic colour depends upon the amount of the particular element present in the solution, and the information is recorded by means of a photocell. This physical method of chemical analysis is also ideal for testing trace elements such as pollutants.

Ore Processing

Each ore is a processing challenge. To yield its metal wealth, the ore demands a specific adaptation of the three basic methods of metal separation—physical, chemical and electrical—known to man.

But the challenge cannot always be met by man. In Canada, as in most countries throughout the world, there are many large deposits that cannot be mined, simply because there are no known methods of separating the metal from those specific ores. Or existing methods are economically unattractive because of the low metal content.

The Mines Branch is doing much to bring such orebodies into production, either by devising means to concentrate the metal component until it can be economically treated by common methods, or by developing new processing procedures.

The metal component of an ore is generally concentrated by such physical techniques as screening, gravity separation, magnetic and electrostatic separation. The last two methods are based on the ability of the metal to be either magnetized or to accept an electrical charge.

As one example, the Mines Branch succeeded in bringing a large deposit of low-grade iron ore in north-western Quebec into production by using several stages of grinding and magnetic separation to raise the iron content to an acceptable level.

Again, one of Canada's rare tungsten mines is in operation in New Brunswick today as a direct result of efforts by the Branch to concentrate the tungsten by gravity and recover by-products by selective flotation in a profitable manner.

Flotation, probably the most versatile physical-chemical concentration method, is based on the selection of a liquid or froth in which either the metal component alone or all others will float. It is a skilled science that demands intimate knowledge of the surface properties of metal complexes and of liquid media.

The choice of flotation agent can often determine the profitability of a mining operation, since the sharper the separation of components in flotation the fewer the steps required in subsequent processing.

Flotation studies by the Branch, for example, have helped to bring into production the 0.5%-copper orebody in the Highland Valley of British Columbia.





Processing copper-zinc ore by flotation at Lake Dufault Mines Ltd., Noranda, Que. The ore-bearing liquid is fed into the flotation cells through pipelines. The metal-bearing mineral is floated off while the waste material sinks to the bottom of the trough. The minerals are then filtered and dried, then sent for smelting.

Chemical Extraction

Very few metals are obtained pure from the physical treatment of specific ores. Most metals have a more tenacious hold and require chemical processing.

Leaching is probably the most common chemical treatment. In theory, it is a very simple low-cost separation method. The metal-containing portion of the ore is treated with a liquid which preferentially dissolves only the metal component. But, in fact, leaching is an exact science that is controlled not only by the selection of the best solvent from thousands of

possibilities, but also by temperature, pressure, acidity-alkalinity ratio known as pH, composition of ore and similar factors.

Once in solution, the metal can be precipitated in pure solid form by chemical reagents or by artificially stimulating an exchange of ions among the chemical components of the solution.

The Mines Branch spends much concentrated effort on finding leaching reagents for unusual ores, selecting more effective or more economical solvents for existing leaching procedures, and especially on improving the recovery yield of metals from the solvents.

One of the more unusual and perhaps spectacular leaching studies carried out by the Branch is the separation of uranium from its iron-containing ores. When partially-oxidized iron (ferrous oxide, FeO) and fully-oxidized iron (ferric oxide, Fe_2O_3) are both present in the ore, separation of the uranium by leaching becomes difficult and expensive, since the most effective, low-cost solvent for uranium is sulphuric acid which also dissolves ferrous oxide. The Mines Branch, however, discovered that a certain strain of bacteria will convert ferrous oxide to ferric oxide at very low cost in a relatively short period of time. Once the action is completed, it is possible to leach out the uranium with sulphuric acid and to bring it out of solution by an ion exchange.



This procedure is today a definite cost saver for the uranium industry. In the future, bacterial oxidation of ores may prove equally effective for the extraction of other metals, such as copper, for example. The Mines Branch is working on it.

Bacterial leaching is used to extract uranium from coarse sulphide-bearing ores. In this experimental set-up, the leach solution is recycled over the ore in a percolation column to study the effect of particle size on the rate of extraction.

(Insert). Bacteria of the *Ferrobacillus*-*Thiobacillus* group from uranium mine water.

Smelting

Metal oxides, especially those of chemically reactive metals such as iron and aluminum, are difficult to separate. The chemical bonds such metals form with oxygen are very tight and strong and demand much energy in the form of heat to break. In the case of iron, for example, the heat of a blast furnace is required to melt the oxide and release the metal in the presence of a suitable reducing agent. The Mines Branch carries out much fuel research including studies on the production of suitable grades of metallurgical coke or char for the reduction of iron.

Since iron is most commonly found as an oxide in nature, smelting is the most effective low-cost large-volume production method for the metal.

The Mines Branch is responsible for a major break-through in steel-making in recent years. Its experts developed an oxygen probe which, by measuring the free-oxygen content of the melt in the furnace, determines quickly and accurately when the steel is 'cooked' ready for pouring. Previously, steelmen had to rely on lengthy laboratory analyses or on guesswork based on experience.

For the steel-producer, the oxygen probe is a significant cost saver in terms of reduced waste from reject ingots, shorter batch cycles in the furnace and a better product. The probe is now produced commercially by a Canadian firm.

Fabrication

Pure metals, extracted from ores, are generally blended with small additions of other metals to form alloys with new or improved properties.

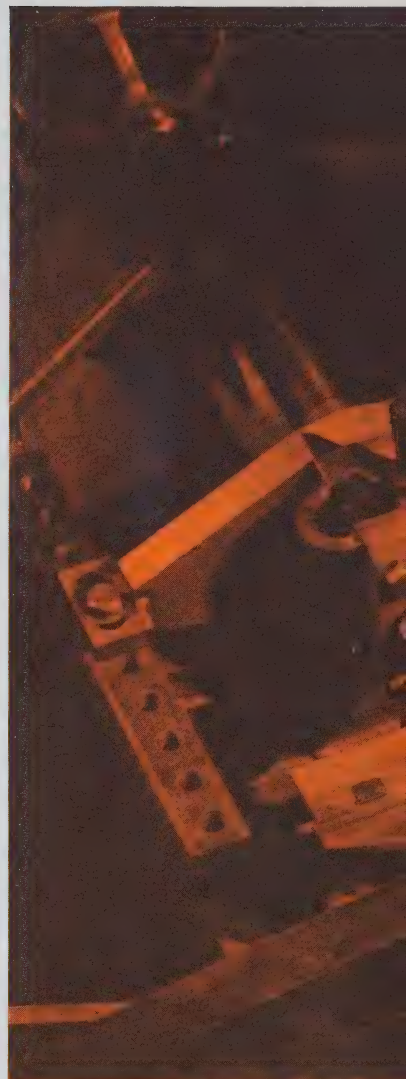
Metal alloys are then converted into useful products by casting into shapes, rolling into sheet, extruding into structural beams, etc.

The Mines Branch conducts research in all phases of metal fabrication. For example, in the casting of metals, a Branch study by X-ray film of the flow of metal into the mould has revealed how metal 'freezes' inside the mould and has indicated ways by which conventional mould design can be altered for an improved product.

Similarly, a study of the heat flow during the welding of metal has shown how changes in welding procedures can at least partially overcome the structural degradation of the metal as a result of the heat of welding.

The Branch is conducting a continuing study on the causes of metal failures. It devises more stringent, more effective test methods to predict failures before they occur.

The Mines Branch will also act as consultant to determine the causes of metal failure occurring for no known or apparent reasons.





On a fatigue-testing machine in the Physical Metallurgy Laboratory of Mines Branch a technician submits a metal component to stress.

"Fatigue" life is one of the basic characteristics for which metal parts must be tested — a short-lived train axle or a wing component of a plane could prove disastrous. Since more than 80 per cent of metal failures are due to fatigue, the intensity and number of stresses they can undergo before breaking must be carefully determined and noted.

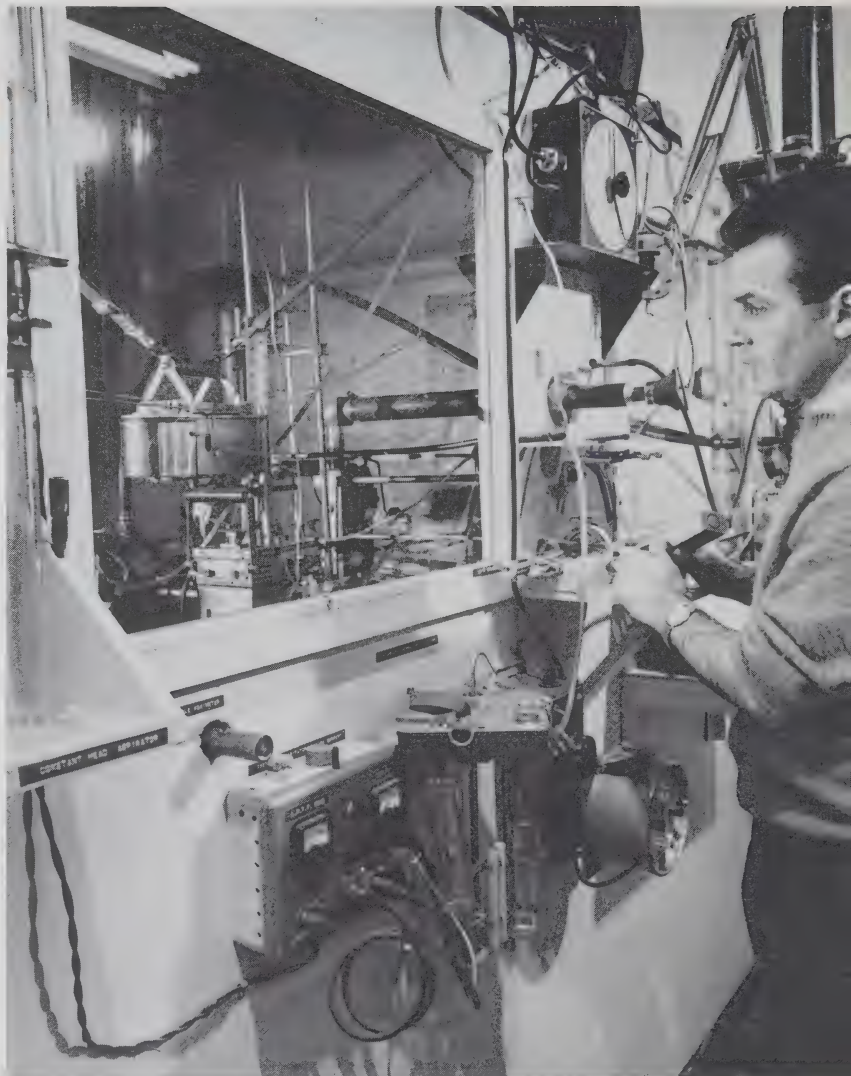
Pollution and Environmental Protection

Although metals are an indispensable part of the Canadian economy, the public is increasingly demanding that environmental and sociological as well as economic requirements be considered in their extraction and processing.

Much progress has already been made in the stabilization and reclamation of waste products from mining and metallurgical industries. For instance, it is feasible to grow grass and crops on some of these materials. Land once scarred by mining operations can be landscaped and restored to a state even better than before. Now, when new operations are planned, attention is given to immediate as well as long-term protection against environmental damage.

Improved methods of smelting ore, converting gases into useful by-products, collecting dusts, increasing the removal of acid-forming constituents from solid waste products, and returning waste solids to fill underground openings are being adopted to minimize pollution.

A survey on environmental control in the mining and metallurgical industries in Canada conducted by the Mines Branch in Ottawa on behalf of the National Advisory Committee on Mining and Metallurgical Research



Air samples from a dust chamber are analyzed in the Mines Branch laboratory at Elliot Lake, Ont.

Because of their working environment, miners are susceptible to lung diseases, and the Branch has undertaken an environmental control program toward improving the quality of mine air. Other industrial countries are reviewing the standards for mine air, and to ensure that these standards are realistic for Canadian conditions a comprehensive knowledge of dust and radiation hazards is necessary.

showed that for the period 1971-75 these industries are planning to spend between \$400 and \$500 million on control and improvement of the environment.

The Mines Branch is conducting research to reduce pollution of air, soil and water by the mineral- and metal-processing industries. The program includes studies to modify existing processes for eliminating or reducing pollutants to acceptable levels — or alternatively, to find means of converting them to useful products. Results have been encouraging.

The steel-making industry, which annually produces about 11 million tons of steel, discharges large quantities of pollutants into the air. The Mines Branch studied the problem and suggested methods of abatement.

Scientists have found that injection of limestone into the combustion units of thermal power plants can partly control emissions of stack gases. They have shown that the sulphur-dioxide content can be converted into a relatively harmless discardable calcium-sulphate product.

Studies have been made to select regenerative sulphur-dioxide absorbents that can yield either elemental sulphur or concentrated sulphur dioxide on regeneration. Zeolon, an acid-resistant synthetic, shows considerable promise for removing dilute sulphur dioxide from flue gases. It performs well at high temperatures and has excellent regenerative properties.

Magnesium oxide is being investigated for the removal of sulphur dioxide from dilute smelter gases. The metal oxide powder can be made to react quantitatively with sulphur dioxide to form magnesium sulphate. The sulphur may then be recovered as either the dioxide or the element as market conditions dictate.

Coke is essential in the metallurgical industry. Its manufacture by conventional methods is a source of serious air pollution, and hence the industry is faced with high construction and maintenance costs to conform to pollution-abatement requirements. New techniques of preheating coal and form-coking being developed by the Mines Branch may alleviate and ultimately eliminate these problems.

Normally, iron-sulphide concentrates are heated to produce iron with sulphur dioxide as a by-product. This can result in air pollution if there is inadequate control. An alternative method of extracting iron from such concentrates has been developed by the Mines Branch. This is based on acid leaching. It avoids the production of sulphur dioxide, and permits recycling of the hydrochloric acid employed.

A study of nitrogen fumes from steam boilers has shown that toxic nitrogen gases can be reduced by almost 90 per cent if the boiler is operated at the lowest practical temperature.

Chlorine vapors from aluminum smelters can be brought to an acceptable level by stopping the addition of



Coke is discharged from a moveable-wall test oven. Used in the conventional iron-producing process, coke must be evaluated for the benefit of both producer and consumer. Here, the expansion pressure of a coke sample is measured to determine how strong the walls of a commercial coking unit must be made. The Mines Branch is investigating entirely new methods of coking, particularly the "form-coking" process, involving special methods of up-grading and agglomerating coal.

chlorine as a fluxing agent as soon as 95 per cent of the cleaning action by chlorine has been completed. This point can be quickly calculated in advance.

What it means to Canadians

Canadians enjoy one of the highest standards of living in the world. To a significant degree, this prosperity and security are due to our ability to find, extract, transform and market the mineral wealth hidden beneath our soil.

Canada exports approximately \$5 billion worth of mineral commodities per year. Some of these commodities are raw materials — they are exported as they come out of the ground. Most, however, have been made saleable by being treated and transformed to some degree, and some of the technology that goes into this treatment has been developed in the Mines Branch of the Department of Energy, Mines and Resources. This applies to the coking of Canadian coals and the pelletizing of iron ore — both treatments preceding the combination of coke and iron ore in the blast furnace.

The design of mines and mine safety, too, have been greatly improved with the aid of Mines Branch studies.

Thus the work of the Mines Branch helps earn for Canada large amounts of export dollars, an income that is diffused through numerous occupations.

The exploration of the Arctic demands topnotch equipment and machinery that will withstand the savage attacks of cold and ice. Mines Branch spe-

cialists have tested and developed alloys that will perform safely and dependably under these adverse conditions, thus ensuring a Canadian presence in our Far North. The same type of service has been performed for the Canadian Armed Forces.

New or improved methods of treating low-grade ores developed by the Branch have brought new industry to parts of Canada experiencing economic difficulties. Thus, for example, a treatment method was developed for a strontium-sulphate deposit on Cape Breton Island.

Mines Branch work has resulted in the reduction of harmful effluents and gases in ore treatment. For example, streams in gold-mining areas are now purer because the discharge of cyanide by gold-milling plants has been reduced through Mines Branch research.

Whatever Canadians do, wherever they go they are the unknowing beneficiaries of Mines Branch research and experimentation. When the Royal Canadian Mint decided to switch from silver to nickel 25-cent pieces, the Branch helped to make sure that the new coins would work in vending machines. When housewives in Ontario light up their gas stoves, the gas has come from Alberta through pipes made secure and durable with the help of Mines Branch research. Trains travel more safely over steel rails and bridges because Mines Branch investigation of steel failure has brought practical results. If wild birds no longer die from swallowing birdshot scattered

by hunters it is because Mines Branch experts have removed poisonous components from the pellets.

Numerous industrial processes have been improved by Mines Branch research, thus helping Canadian industry to remain technologically and commercially competitive with the rest of the world and assuring the Canadian people a prosperous economy and a safe and healthy environment.

Photos : George Hunter for Mines Branch.
Design : Century Art Studio, Montreal.

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